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Rebekah Hammack
Montana State University, rebekah.hammack@montana.edu

Juliana Utley
Oklahoma State University, juliana.utley@okstate.edu

Toni Ivey
Oklahoma State University, toni.ivey@okstate.edu

See next page for additional authors

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elementary engineering education, in-service teacher, professional development, Draw-an-Engineer

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Rebekah Hammack, Juliana Utley, Toni Ivey, and Karen High

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Elementary Teachers' Mental Images of Engineers at Work

Rebekah Hammack[1], Juliana Utley[2], Toni Ivey[2], and Karen High[3]

[1]*Montana State University*
[2]*Oklahoma State University*
[3]*Clemson University*

Abstract

The purpose of the current study was to determine the impacts of a multiple-day engineering-focused professional development program on elementary teachers' perceptions of the work of engineers and their use of mathematics and science. Data were collected in the form of drawings of engineers prior to and immediately after the professional development program as well as an open-ended exit survey at the end of the program. Participants' drawings were scored in the following areas: use of mathematics, use of science, and work of an engineer. Wilcoxon signed-rank tests revealed that the only significant change between measures was in "work of an engineer," with participants' drawings representing more expanded conceptions after completing the professional development program. An analysis of exit survey responses indicated that participants still had a limited understanding of the complex relationships among engineering, science, and mathematics.

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Introduction

Since the release of *A Framework for K–12 Science Education* (National Research Council, 2012) and the *Next Generation Science Standards* (NGSS Lead States, 2013) there has been an increase in the number of states incorporating engineering into their science standards (Moore et al., 2015). The incorporation of engineering into science standards presents challenges because many teachers, particularly elementary teachers, have had minimal preparation for teaching engineering (Banilower et al., 2018; Hammack & Ivey, 2019) and hold misconceptions about the work of engineers (Cunningham et al., 2006; Hammack & Ivey, 2017; Nadelson et al., 2016). At the elementary level, engineering is often incorporated into the curriculum in the form of engineering design challenges (Lachapelle & Cunningham, 2014). However, teachers can have difficulty connecting engineering to science and mathematics standards (Guzey et al., 2016). Engineering is inherently interdisciplinary and can provide opportunities for teachers to integrate different disciplines (Cunningham & Kelly, 2017). Understanding elementary teachers' perceptions of the work of engineers and the ways in which they believe engineers use mathematics and science will be useful when designing professional learning experiences to help pre- and in-service teachers meaningfully integrate science, technology, engineering, and mathematics (STEM) disciplines. In the following sections, we identify the purpose of the study and provide an overview of the background literature that guided the design of this work.

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Purpose of the Study

The purpose of the current study was to determine the impacts of an engineering-focused professional development (PD) program on in-service elementary teachers' perceptions of the work of engineers as measured by mental images depicted in their drawings of engineers before and after the program. More specifically, the study sought to answer the following research questions: (1) What mental images do in-service elementary teachers hold of the work of engineers? (2) How do in-service elementary teachers describe the way engineers use mathematics and science in their work? (3) Do these mental images and descriptions change over the course of an engineering-focused professional development program?

Background Literature

The 2018 National Survey of Science and Mathematics Education (NSSME) reports worrying statistics related to elementary teachers' beliefs about their preparedness to teach engineering (Banilower et al., 2018). According to NSSME, only 3% of elementary teachers have had any college coursework in engineering, only 3% hold a college degree in either science or engineering, and only 3% hold a degree in science or engineering education. It is not surprising, then, that only 3% of elementary teachers report feeling very well prepared to teach engineering, with more than half reporting that they do not feel adequately prepared. Slightly more surprising is the statistic that only 9% of elementary teachers feel well prepared to develop their students' awareness of STEM careers. This is troublesome considering that youth begin making career decisions prior to middle school (Wyss et al., 2012) and that demand for STEM-related jobs is projected to be higher than for non-STEM-related jobs (Torpey, 2018). Understanding elementary teachers' perceptions of STEM careers, including engineering, will be important when identifying ways to support the development of elementary teachers' understanding of STEM careers and their ability to support student awareness of such careers.

STEM Integration and the Nature of Engineering

The framework guiding the current study combines Moore and colleagues' (2014) *STEM Integration Framework* and Pleasants and Olson's (2019) *Nature of Engineering*. According to Moore et al. (2014), students can meaningfully learn mathematics and science when it is connected to realistic engineering problems through STEM integration. They define integrated STEM education as "an effort by educators to have students participate in engineering design as a means to develop technologies that require meaningful learning and an application of mathematics and/or science" (Moore et al., 2014, p. 38). Often there is a disconnect between the science and mathematics that is taught in schools and their real-life applications. Moore et al. (2014) argue that engineering can be a vehicle to connect school science and mathematics with real-life science and mathematics. This process requires educators to have an understanding of the nature of engineering so that they can facilitate students to cross disciplinary boundaries when solving design problems (Moore et al., 2014).

It is important for teachers to understand the nature of the engineering discipline in order to design and implement effective instructional activities. Such integrated activities can engage students and enhance their science and mathematics knowledge while building a better understanding of the nature of engineering. Pleasants and Olson (2019) conceptualize the nature of engineering (NOE) as including "issues relevant to the structure of the engineering discipline: what engineering is, how it works, how engineers conduct their work, the relationship between engineering and other fields of study such as science, and how engineering influences and is influenced by society" (p. 146). Pleasants and Olson (2019) compiled a list of nine disciplinary features of engineering: design in engineering; specifications, constraints, and goals; sources of engineering knowledge; knowledge production in engineering; the scope of engineering; models of design processes; cultural embeddedness of engineering; the internal culture of engineering; and engineering and science. Pleasants and Olson (2019) argue that if engineering is expected to be taught as part of science classes (as dictated by Next Generation Science Standards) then it is important that the NOE discipline is an explicit part of instruction to allow students to recognize the differences between science and engineering.

Explicit NOE instruction will require that teachers have a strong understanding of the NOE. While studies specific to the NOE framework proposed by Pleasants and Olsen (2019) are needed, there have been related studies that focus on perceptions of engineering. These studies indicate that much of the general United States population does not understand the work of engineers, and often confuses the work of engineers with the work of engineering technologists (National Academy of Engineering, 2015) or the work of scientists (Oware et al., 2007). Researchers report that teachers are not immune to these misconceptions and have limited familiarity with engineering (Hammack & Ivey, 2017; Yasar et al., 2006) and possess limited views of the work of engineers (Cunningham et al., 2006; Hammack & Ivey, 2017; Nadelson et al., 2016). Elementary teachers have been reported to have an overly broad view of the work of engineers, confusing it with the work of construction workers and automotive mechanics (Cunningham et al., 2006). Further, some elementary teachers hold misconceptions about who can become an engineer, reserving the profession for only those who are "super smart" (Cunningham, 2009) or from higher socioeconomic backgrounds (Hammack & Ivey, 2019). It has been suggested that teachers' perceptions of engineering influence their approaches to teaching engineering, which could then affect students' perceptions of engineering (Cope & Ward, 2002). Further, teachers' perceptions about how mathematics and science are used in engineering could influence the ways that teachers introduce connections to mathematics, science, and engineering to their students.

Draw-An-Engineer Test

Individuals' drawings have long been used as a form of assessment of mental images ranging from the Draw-A-Man test (Goodenough, 1926) to the Draw-A-Scientist test (Chambers, 1983; Mason et al., 1991) and, more recently, the Draw-An-Engineer test (DAET) (Knight & Cunningham, 2004). Studies using DAET highlight stereotypical misconceptions that children hold of engineers, such as people who build and fix things, as well as the tendency to include images of white, male engineers who are working alone more often than drawings of women, minorities, or people working in groups (Capobianco et al., 2011; Fralick et al., 2009; Karatas et al., 2011; Newley et al., 2017; Pekmez, 2018). In a study of middle school girls who had participated in an after-school engineering mentoring program, Hammack and High (2014) found that participants were more likely to draw female engineers. This could be because all mentors and guest speakers who participated in the program were female engineers or engineering students. After analyzing the drawings of 396 children from grades 1–5 in urban and suburban schools, Capobianco et al. (2011) found that girls were more likely to draw female engineers than boys were; however, more girls drew male engineers than female engineers. Further, Capobianco et al. (2011) reported that fourth and fifth graders were more likely to represent engineers as designers; however, this representation was only found in roughly 17% of drawings. Karatas et al. (2011) utilized drawings and semi-structured interviews with 20 sixth-grade students to provide insight into children's understanding of the NOE. They found that children's perceptions of engineers were not well formed and were likely to change during the course of a single interview spanning 35–70 minutes.

While not prevalent, versions of DAET have been used with K–12 teachers to identify their perceptions of engineers (Carreno et al., 2010; Pizziconi et al., 2010; Pleasants et al., 2020). These studies have suggested that teachers hold stereotypical misconceptions similar to children's (Carreno et al., 2010) and that relatively few teacher drawings indicate connections between engineering and society (Pizziconi et al., 2010). Pleasants et al. (2020) used DAET to compare elementary teachers' representations of engineers before and after participating in an engineering-focused PD program. They reported that from pre- to post-program, teachers' drawings were more likely to include aspects of an engineering design process and clearer representations of the processes engineers used in their work. The present study uses a modified version of the DAET with elementary teachers, which adds to the limited literature in this area.

Methodological Concerns with Drawing-based Instruments

As noted above, the use of DAET with students, and particularly teachers, is a relatively new area of research. However, it is believed that some of the limitations associated with using the Draw-A-Scientist test, which is more widespread, can be applied to the DAET, thus warranting discussion here. Drawings may not represent a complete view of the drawer's thoughts (Losh et al., 2008; Reinisch et al., 2017; Walls, 2012) and the use of multiple instruments could allow researchers to have a more complete view of participants' thinking (Walls, 2012). Reinisch et al. (2017) advise against only using content analysis of participants' images and suggest collecting additional information through open-ended prompts and/or focus group interviews. Further, Losh et al. (2008) warn against using drawings to draw conclusions about children's internal conceptions such as self-efficacy. However, Losh et al. (2008) do note that drawings can be a valid tool to identify stereotypes held by children.

DAET can be used as an analytical tool to compare changes in individuals' perceptions over time and inference validity can be enhanced when the participant-produced drawings are used in conjunction with participants' written or oral descriptions of the drawings (Tirupalavanam, 2011). As suggested by Tirupalavanam (2011) and Losh et al. (2008), we believe that using DAET, in conjunction with other open-ended prompts, can provide valuable information to researchers. In the current study, we seek to identify participants' basic conceptions of how engineers use mathematics and science in their work and how these perceptions change over time. To combat concerns associated with the Draw-A-Scientist test and similar tests, we do not attempt to make conclusions about participants' internal conceptions and we use written descriptions provided by participants in addition to their drawings. We argue that even if the data collected from the participants do not provide a full view of participants' thoughts, the changes identified from pre- to post-program participation are still valuable.

Engineering-focused Professional Development

Numerous studies have reported on the positive influences of engineering PD on teachers' engineering teaching efficacy (Gardner et al., 2019; Utley et al., 2019), understanding of engineering design (Yoon et al., 2013), engineering content knowledge (Duncan et al., 2011; Macalalag et al., 2010; Zarske et al., 2004), and science content knowledge (Macalalag et al., 2010; Utley, Ivey, Hammack, & High, 2019; Zarske et al., 2004). These and other studies have led to the development of a few engineering-specific PD models that guided the design of the PD used in the current study.

Based on five years of Engineering is Elementary (EiE®) PD research, Sargianis et al. (2012) identified what they believed to be best practices for engineering PD as (a) engaging participants in active, hands-on learning experiences, (b) engaging participants as learners, (c) modeling effective pedagogical strategies, (d) using formative assessment strategies during activities, (e) providing opportunities for participants to build foundational knowledge, (f) using the student hat and teacher hat, (g) implementing collaborative group work and discussions, (h) including time for debriefing and reflection, and (i) providing time to plan future classroom implementation. Additionally, based on a thorough review of the literature, Reimers et al. (2015) developed the Standards for Preparation and Professional Development for Teachers of Engineering. According to these standards, engineering-focused PD should (a) address the fundamental nature of engineering, (b) build participants' engineering pedagogical content knowledge, (c) provide a context for utilizing engineering design to teach standards in other disciplines (e.g., mathematics, science, reading), (d) empower teachers to identify appropriate instructional and assessment resources, and (e) be aligned to current research on teaching and learning. The current study, which provided PD to teachers based on the models presented by Sargianis et al. (2012) and Reimers et al. (2015), explores teachers' perceptions of mathematics, science, and engineering and offers recommendations for PD.

Methods

Description of Participants and Professional Development

Participants included 30 in-service elementary teachers from a Midwestern state who completed a series of engineering education workshops consisting of two full-day Engineering is Elementary (EiE®) trainings and a half-day Family Engineering Night (http://www.familyscienceandengineering.org/) training. Fourth-grade teachers received training on two EiE® modules (*A Slick Solution: Cleaning an Oil Spill* and *A Long Way Down: Designing Parachutes*) and fifth-grade teachers received training on two modules (*An Alarming Idea: Designing Circuits* and *To Get to the Other Side: Designing Bridges*). Four female facilitators, including a middle-school engineering teacher, science education faculty, mathematics education faculty, and chemical engineering faculty conducted the PD. All four facilitators were familiar with the EiE® curriculum and had previous experience providing engineering-focused PD activities for teachers. The science and mathematics education faculty members had completed EiE® facilitator training at the Boston Museum of Science prior to the PD to ensure that each EiE® training was facilitated by a trained facilitator. Facilitators followed the EiE® PD model and supplemented the training by having focused science content conversations with the teachers as they completed the training. For example, during the *An Alarming Idea: Designing Circuits* EiE® curriculum training, the facilitator purposefully held content conversations focused on circuit components and types to engage teachers' prior knowledge.

Participants were predominately female (80%) and white (83%) or Native American (17%) and all taught either fourth or fifth grade. Participants ranged in years of teaching experience with 28% having 0–5 years of experience, 48% having 6–14 years of experience, and 24% having 15 or more years of experience. With the exception of one, all participants attended the PD program with at least one other teacher from their school. Only one participant had previously attended an engineering-focused PD program. Baseline data were collected from participants to determine which subject they were most comfortable teaching and indicated that 47% were most comfortable teaching math, 20% were most comfortable teaching science, 20% were most comfortable teaching language arts, 10% were most comfortable with social studies, and 3% were most comfortable with fine arts. This is in contrast to Wilkins (2009) who reported that elementary teachers tended to prefer teaching reading and language arts to other subjects.

Measures

Modified Draw-An-Engineer Test (mDAET) and Rubric (mDAET-R)

The mDAET and mDAET-R (Thomas et al., 2016) was developed to explore elementary students' knowledge and understanding of the work of engineers. This mDAET and mDAET-R differs from the DAET instrument of Knight and Cunningham (2004) and the coding schemes developed to assess them in that DAET places emphasis on the artifacts present in the drawing and the physical characteristics and actions of the engineer. This mDAET, however, was designed to assess participants' understanding of the work conducted by engineers, particularly how engineers use mathematics and science as part of their work. Thus, the mDAET-R focuses on how individuals describe the ways in which mathematics and science are used by the engineers depicted in their drawings. The mDAET asks the individual to draw three different depictions of engineers at work and then describe what the engineer was doing, how they were using mathematics, how they were using science, and to specify the gender of their engineer. The multiple depictions allowed researchers to gain deeper insight into the individual's knowledge and understanding than could be gained with a single drawing. The mDAET-R consists of four elements scored along a continuum. Two of the elements score the individual's response to how an engineer uses mathematics and how they use science. Scores on these two elements range from 0 to 2, with a score of 0 indicating no reference to mathematics/science, a score of 1 indicating that the response identifies a mathematics or science skill or concept an engineering might use, and a score of 2 indicating that the response illustrates an application of mathematics/ science in the context of the engineer's work. The work of an engineer continuum ranged from a vague depiction (score = 0) to an advanced conception (score = 3). A score of 1 on the work of an engineer element indicates that the response contains a naïve conception of engineers (i.e., mechanic, technician). A score of 2 represents a basic conception in which the response indicates a specific discipline of engineering (i.e., chemical, electrical) or an example of work an engineer might perform (i.e., design a new device). However, the level 2 response does not include a reason why the engineer would perform the indicated work. The level 3 response includes a reason (or context) for the engineer's work. The final element is the gender stereotype of an engineer, which ranges from no response or conflicting information (score = 0) to the individual suggesting that gender was irrelevant (i.e., it could be a boy or a girl) or that engineers work in teams (score = 3). For this item, participants are asked the following question: Is the engineer a girl or a boy? A score of 1 on the gender stereotype represents a traditional conception of an engineer as an individual male, while a score of 2 indicates a non-traditional conception of a female engineer. Additionally, in further research Thomas et al. (in press) found that the rubric, with rater training, has good interrater reliability.

Exit Survey

At the end of the program, teachers completed an exit survey and answered the following survey prompt: "Is there a relationship between mathematics, science, and engineering? Explain why or why not."

Data Collection and Analysis

Researchers utilized a pre-/post-test research design. Participants completed the mDAET prior to receiving any training and immediately after completing the final training day (one month after the first training). Two participants did not complete both sets of drawings and were omitted from the analysis. Two researchers who had attended training on the mDAET scoring rubric independently scored participants' drawings. Upon attempting to score the drawings it became apparent that the mDAET-R, which was designed for use with elementary-age children, was not appropriate for scoring the drawings completed by adults. It should be desired that teachers have a deeper understanding of the work of engineers and the ways in which they use mathematics and science in their work than children, especially if we expect teachers to relay this knowledge to the children they teach. Therefore, a scoring system with a higher threshold for the work of an engineer and the ways engineers use mathematics and science should be used with adult drawings. As a result, the researchers used a qualitative content analysis approach (Hsieh & Shannon, 2005) to code the drawings to identify categories related to three different concepts: (1) engineers' use of mathematics, (2) engineers' use of science, and (3) work of an engineer. Researchers chose not to score the gender stereotype question because the focus of the current study was on identifying how teachers' perceived the work of engineers and the ways in which mathematics and science are used by engineers.

To score the drawings, we examined the instrument holistically, considering both the image depicted and the written descriptions that were included. Using NOE as our framework, our initial goal was to identify the spectrum of conceptions present in the drawings and use that to identify categories that represented varying levels of understanding relevant to each of the three constructs for which we were coding. Researchers scored each drawing separately (three per participant) for each of the three concepts. The researchers began by sorting the drawings into categories that represented different levels of understanding and describing the characteristics of the drawings that were in each resulting category. Multiple rounds of sorting and describing were completed to refine the piles and resulting category descriptors. Resulting scores were compared and the researchers discussed any drawings that did not receive the same score until consensus was reached.

For example, for the science construct, researchers began by sorting responses into two piles: one that was too vague to interpret or that had no science present and one that had at least some science present. From there, the pile that had science present was further sorted into piles that represented different levels of responses for science. These piles then went through multiple rounds of sorting and describing until the researchers felt that the piles and resulting categorical descriptions were complete. The same process was conducted for the mathematics and work of an engineer constructs.

To determine if differences existed in participants' drawings from the beginning to the end of the workshop, each qualitative category was assigned a numerical score, with values increasing according to the complexity of the category. Due to the small sample size and non-normal distribution of data, nonparametric statistics were used. Sample sizes above 20 have been reported to be adequate for use in nonparametric tests (Fahoome, 2002; Whitley & Ball, 2002). As such, we utilized the data with pairwise Wilcoxon signed ranks to determine if significant changes occurred between data collection points.

Responses to the two open-ended survey questions were printed onto cards which were used during the coding process (Creswell, 2007). First, attribute coding was used to log essential demographic information about the participants for future reference (Saldana, 2013). Each card was coded with the participant's gender, ethnicity, and years of teaching experience. Next, multiple rounds of open coding were used to generate and refine a list of codes (Saldana, 2013) that were then reviewed through axial coding to identify relationships between the open codes and generate categories (Strauss & Corbin, 1990).

Results and Discussion

Participants' mDAET drawings were scored with the accompanying mDAET-R. When using the mDAET-R to score participating teachers' drawings, there was no significant change between pre- and post-program drawings for use of science, use of mathematics, or work of an engineer. When examining post-program mDAET-R scores, it was noted that the post-program median scores for the use of science and use of mathematics were both 1.67 out of a possible 2.0, placing participants' conceptions closer to an advanced conception. When examining the work of an engineer, the median post-program score was 2.33 out of a possible 3.0, which placed participants' conceptions between basic and advanced. While these high post-program scores may have been appropriate if the drawings were produced by children, the scores did not accurately reflect the level of understanding that one would expect a teacher to have, indicating the need for a scoring rubric specific to adult participants.

Table 1 presents summary statistics for the categorical coding of the mDAET. Wilcoxon signed ranks test shows that there were no statistically significant changes for use of mathematics ($Z = -1.32$, $p = 0.186$, $r = -0.25$) or use of science ($Z = -1.72$, $p = 0.086$, $r = -0.33$). There was a statistically significant difference in scores for the work of an engineer with a large effect size ($Z = -3.39$, $p = 0.001$, $r = -0.64$), indicating that participants were more likely to hold more expanded conceptions of the work completed by engineers after they completed the PD.

Analysis of drawings for teachers' understandings of the ways in which engineers use mathematics and science (Table 2) in their work revealed three major categories of responses. The first category, *Non-Descriptive*, included no response or a response that was nonsensical in that it did not seem to tie the work of the engineer to mathematics or science. Such responses included: "needs to know how much parts need to be tightened," "in a computer program," "to build height," "build a self-supporting bridge," and "calculate how high this building can go with the design." Figure 1A provides an example of nonsensical responses for both the use of mathematics and the use of science. The next category of responses, *Mathematics/Science without a Purpose*, included descriptions that made vague reference to mathematics or science content or skills that could be construed as used by the engineer; however, there was no mention as to why or how they were used (see Figure 1B). For example, responses in this category included simple listings of mathematics and/or science terms such as measurement, speed, time, circuitry, electricity, scientific process, physics, material strength, and force. Measurement was a term that occurred quite often in this category for mathematics either alone or with other random terms. Within the final category, *Mathematics/Science with a Purpose*, teachers provided a purpose for the use of mathematics/science as related to the work of their depicted engineer; however, this was not always within the context of engineering. Figure 1C provides a depiction of one teacher's drawing where an engineering context is present, and the mathematics/science is described within the context of this work. Many of the responses for mathematics dealt with calculating something or

Table 1
Summary statistics for participants' scores on mDAET ($n = 28$) using categorical coding.

	Pre-administration			Post-administration					
Element	**Min.**	**Max.**	**Median**	**Min.**	**Max.**	**Median**	***Z***	***p***	***r***
Mathematics	1.33	3.00	2.00	1.33	3.00	2.17	−1.32	0.186	−0.25
Science	1.33	2.67	1.84	1.33	3.00	2.00	−1.72	0.86	−0.33
Engineering	1.00	2.33	1.67	1.00	4.00	2.33	−3.39	0.001	−0.64

Table 2
Drawing analysis results for use of mathematics and use of science.

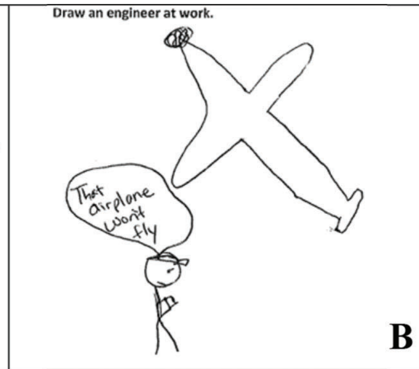
Category	Description of category	Mathematics		Science	
		Pre *N* (%)	Post *N* (%)	Pre *N* (%)	Post *N* (%)
Non-Descriptive	No response provided or no mention of specific mathematics/science concepts or skills such as "I am thinking about the problem" or "In a computer program"	11 (13)	7 (8)	22 (26)	14 (17)
Mathematics without a Purpose	Listing of mathematics/science concepts or skills that could be related to the drawing	48 (57)	47 (56)	45 (54)	43 (51)
Mathematics with a Purpose	Clear precise purpose for the mathematics/ science depicted; applies mathematics/ science skills and concepts to the work depicted	25 (30)	30 (36)	17 (20)	27 (32)

determining cost; similarly, those for science also mentioned figuring/calculating something and determining the type of material that would work best or be cheapest.

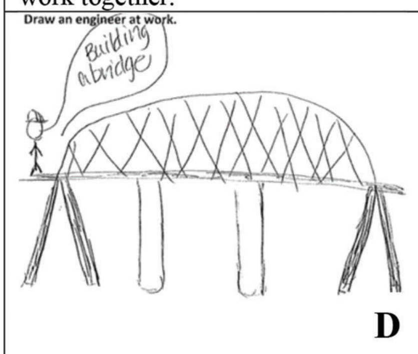
The analysis of drawings for teachers' understandings of the work of an engineer (Table 3) revealed four major categories of responses. Prior to completing the PD, teachers' drawings fell into one of three categories: limited conception, basic (emerging) conception, or intermediate (developing) conception. Half of the pre-PD drawings were categorized as limited conception, as they were either so vague that the participant's conception could not be determined or they misrepresented the work of an engineer as work that is traditionally completed in other professions (e.g., construction workers, mechanics, scientists). Figure 1A is an example of a limited conception image that depicts an engineer as an automotive mechanic. Approximately one-third of participants created drawings that were categorized as basic (emerging), indicating that the participant depicted engineers who were designing or improving a product, but they did not identify a context or specific problem for which the design work was being completed (e.g., "the engineer is designing a treadmill," "She is making the building stronger"). Figure 1D is illustrative of a basic conception because the engineer in the drawing is designing a bridge but there is no specific context or problem necessitating the construction of a bridge. The remaining 16% of drawings were categorized as intermediate (developing) because they depicted engineers who were designing or improving a product within the context of solving a specific problem. The description, however, was undeveloped and did not provide details of how the engineer was developing the solution to the problem. For example, the engineer depicted in Figure 1E is designing a prosthetic arm for a boy who was attacked by a shark, but there is no indication of how the work will be accomplished.

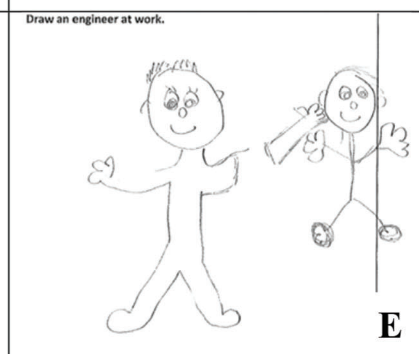
For the work of an engineer construct, each post-program drawing fell into one of four categories: limited conception, basic (emerging) conception, intermediate (developing) conception, or advanced conception. Overall, the post-program drawings represented more advanced conceptions of the work of engineers than the pre-program drawings. Approximately 27% of the drawings were classified as limited, with roughly one-quarter ($n = 6$) of the limited drawings depicting elementary classroom activities. These images of elementary classrooms were included in the limited category because they depicted children at school rather than engineers working in the field. Images of elementary classrooms were absent from the pre-program drawings and their presence in the post-program drawings could indicate that participants were internalizing the PD activities and envisioning themselves teaching engineering in their classrooms. As with the pre-program drawings, roughly one-third of the drawings were categorized as a basic (emerging) conception; however, there were more than double the number of post-program drawings categorized as intermediate (developing) conception. Five drawings fell into the advanced category because they included the problem the depicted engineer was working on, the context in which the engineer was working, and some description of a process the engineer was engaging in to solve the problem. For example, the speech bubble in Figure 1F describes a specific step that the engineer is taking to solve the problem.

The mDAET instrument only asks for a description of how the engineer in the picture is using science and mathematics and is limited in its ability to capture fully how the participant understands the complex relationship among science, mathematics, and engineering. To elicit additional information about participants' views on this relationship, participants were asked to describe this relationship as part of the exit survey they completed on the last day of the program. Most answers were short, with participants' responses falling into three general categories: *interconnectedness of disciplines*, *planning process*, and *engineering as applied mathematics or science*. Table 4 presents a description of each category and examples of representative codes that fell within each category. All participants stated that there was a relationship among mathematics, science, and engineering but the responses were often vague in their description of how the



A	B	C
Engineer The engineer is working on a truck engine.	**Engineer** He is keeping people safe.	**Engineer** He is concerned about the weight of the fuel and the cost of the fuel.
Math Needs to know how much parts need to be tightened, etc…	**Math** Looking for Symmetry	**Math** By calculating the mass of the rocket in relationship to the amount of fuel needed.
Science Needs to make sure all systems work together.	**Science** Drag, Lift, Thrust, etc.	**Science** Calculating the force and type of material needed to use less fuel.





D	E	F
Engineer Designs and oversees the construction of a bridge	**Engineer** This goofy engineer is working to design a prosthetic arm for a unfortunate young man who was attacked by a shark.	**Engineer** He has to design a bridge that is functional, safe, and cost effective.
Math Weight, force, volume, angles	**Math** Measurements/angles/formulas	**Math** Measurements, cost analysis, determining strength
Science Force, motion, wind speed, water, soil, erosion, chemicals	**Science** Technology/mechanics/angles	**Science** Evaluating effect of gravity, weight, properties of material

Figure 1. Examples of participant drawings.

disciplines are connected. For example, one participant wrote, "Everything is interconnected. No subject is lone to itself." Another stated, "math is science, science is math and they both make up engineering." These responses suggest that despite having a basic awareness of the interconnectedness of the disciplines, many participants lack knowledge of the specific ways in which mathematics, science, and engineering knowledge are complementary or the ways in which they can be applied together to solve specific problems.

While the median end-of-program score for these participants on the engineering category of the mDAET was 2.33 (falling between a basic and intermediate conception of engineering), the responses to the relationship among mathematics, science, and engineering question point to a clear lack of understanding of engineering as its own discipline with its own knowledge base. Participant responses such as "Engineering is science. It requires you to define a problem, develop a

Table 3
Drawing analysis results for engineering.

Category	Description of category	Engineering Pre *N* (%)	Engineering Post *N* (%)
Limited	Indicates a mistaken conception of the work of an engineer (e.g., skilled laborer, scientist, mechanic) or vague response (participants' conception could not be determined); drawings of elementary classroom activities	42 (50)	23 (27)
Basic (emerging)	Indicates work that engineers might engage in (e.g., design or improve things) but does not include a context or reference a specific problem to be solved	29 (35)	25 (30)
Intermediate (developing)	Indicates work that an engineer might engage in AND includes at least a basic description of the context or specific problem that is being addressed by the engineer	13 (15)	31 (37)
Advanced	Indicates a firm grasp on the work of engineers and includes the problem the engineer is working on, the context in which they are working, and the process or example actions they are engaging in to solve the problem; connections to the work of the engineer and the societal impacts of that work	0 (0)	5 (6)

Table 4
Category descriptors and illustrative codes for exit survey question.

Category	Description	Example
Interconnection of disciplines	Indicates that the three areas are used together or are related	Yes! You can't have one without the other! Yes! They are connected in so many ways. I can't imagine working in one area and the other not coming up.
Planning process	Indicates that the relationship between the three disciplines is process-related	Yes, the relationship is in the process. Engineering requires the ability to use math and science as one travels through the process. Yes. Both are process driven. Both require planning, testing, rethinking. Both incorporate math.
Engineering as applied mathematics or science	Indicates either that engineering is contained within mathematics or science or that engineering is the application of mathematics or science	Mathematics is a base for creating engineering innovations and engineering is applied science. Yes. Engineering is the applied use of math and science for the purpose of creating or improving technology.

solution, test the solution (or your hypothesis) and then modify" and "Engineering is a form of science" illustrate this lack of understanding. Engineering is not merely applied science and mathematics. Rather, the field of engineering has its own conceptual knowledge that is uniquely different from science and mathematics (Cunningham & Kelly, 2017; Pleasants & Olsen, 2019).

Conclusion and Implications

The aims of this study were to determine the impact of an engineering-focused PD program on in-service elementary teachers' perceptions of the work of engineers, as measured by the mental images depicted in their drawings of engineers before and after completing a PD program. Overall, this study found that these in-service elementary teachers had growth in their conceptions of the work of an engineer but not in their conceptions of the ways in which engineers use mathematics and science. The PD activities utilized EiE® curriculum that "integrates engineering with elementary science topics. Connections with…mathematics can be made" (Engineering is Elementary, 2011, p. 1). The use of EiE® did help teachers increase conceptions of engineers and their work; however, there was a limited change in understanding of engineers' use of science and no change in understanding of engineers' use of mathematics. The engineering pedagogical content knowledge efficacy and science content knowledge of these same teachers increased over the course of the PD (Utley et al., 2019). While the supplemented EiE® training allowed participants to increase their science content knowledge, it did not enhance their portrayal of science in the drawings they produced.

In the drawings, we were not asking participants to apply the science and mathematics in the EiE® curriculum to the work of the engineer. Rather, we were asking for nonspecific examples of engineers at work and the ways they used science and mathematics. Unfortunately, the participants were not making the connection between what they were doing in the PD and how engineers might use mathematics and science as a part of their work. Perhaps because the EiE® challenges were primarily problems students were solving and not examples from real-life engineering, the participants were not applying the PD to the work of real engineers.

Professional developers who are using commercially available engineering curricula, such as EiE®, need to be aware that teachers may need additional support in order to combat the very traditional silo-oriented approaches to mathematics and science instruction and truly integrate engineering, mathematics, and science. This could be as simple as providing explicit real-life examples of the work of engineers and dedicated reflection time for participants. In this case, EiE®-based PD was successful at introducing participants to engineering, as evidenced by the enhanced conceptions represented in their drawings over time. However, the PD was not as effective at improving conceptions of the ways engineers use science and mathematics in their work and should be adjusted to allow for explicit NOE reflections. If teachers have trouble making these connections, then their students may also have trouble making these connections. This points to a need for PD providers to focus on helping teachers make connections between the engineering curriculum they are using and the real-life examples of the integrated nature of science, mathematics, and engineering.

Further, there is need for an analysis of current K–12 engineering curricula to explore how well the curricula connect science and mathematics content to the work of engineers. Curriculum developers that indicate their curriculum is integrated should ensure that the mathematics and science content is truly integrated and provide opportunities for students to see how they are used within the work of engineers. Moore et al.'s (2014) work provides a framework for developing and assessing integrated STEM curricula. As the NOE construct (Pleasants and Olson, 2019) continues to be developed and refined, it will be important for K–12 engineering curricula to align to NOE dimensions.

While instruments eliciting mental images, such as the mDAET, can provide insight into teachers' perceptions of the work of engineers, these instruments are limited by their static nature. Further, the mDAET scoring rubric that was developed for use with children may not be sensitive enough to capture growth in teachers' perceptions of the work of engineers as it can in elementary students. Because the mDAET was developed for use with elementary-age children, additional research should be conducted to determine how the mDAET instrument and rubric might best be modified for use with teachers. Conducting follow-up interviews with participants after they complete the mDAET could provide additional information about how the participants view the work of engineers and the relationship among mathematics, science, and engineering. Additionally, further study is needed to see if modification of prompts would alter results.

Another limitation of this study is its relatively small sample size and the teachers' indication that they were most comfortable teaching mathematics and science. Additional studies with more elementary teachers are needed to gain a more generalized understanding of their conceptions of the work of engineers.

Author Bios

Rebekah Hammack is an assistant professor in the Department of Education at Montana State University. Dr. Hammack conducts research on children's STEM identity development and teachers' STEM teaching efficacy, particularly at the K–5 level.
Email: rebekah.hammack@montana.edu

Juliana Utley is a professor and Morsani Chair of Mathematics and Science Education in the School of Teaching, Learning, and Educational Sciences at Oklahoma State University.
Email: juliana.utley@okstate.edu

Toni Ivey is an associate professor in the School of Teaching, Learning, and Educational Sciences at Oklahoma State University. Her research interests include science teacher professional development, with an emphasis in elementary science education, geoscience education, and engineering education.
Email: toni.ivey@okstate.edu

Karen High is a professor in the Department of Engineering and Science Education at Clemson University. Dr. High's technical research focuses on sustainable chemical process design, computer-aided design, and multi-criteria decision making, while her educational research focuses on faculty development and mentoring, critical thinking and communication skills, and promoting women in STEM.
Email: khigh@clemson.edu

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